(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 422 228 A1**

(12) **EUROPEAN PATENT APPLICATION published in accordance with Art. 158(3) EPC**

(21) Application number: **90901024.1**

(22) Date of filing: **28.12.89**

(86) International application number: **PCT/JP89/01333**

(87) International publication number: **WO 90/07636 (12.07.90 90/16)**

(51) Int. Cl.5: **F01L 9/04**, F16K 31/06, H01F 7/16

(30) Priority: **28.12.88 JP 334958/88**

(43) Date of publication of application: **17.04.91 Bulletin 91/16**

(84) Designated Contracting States: **DE FR GB**

(71) Applicant: **ISUZU CERAMICS RESEARCH INSTITUTE CO., LTD.**
**8, Tsuchidana**
**Fujisawa-shi Kanagawa 252(JP)**

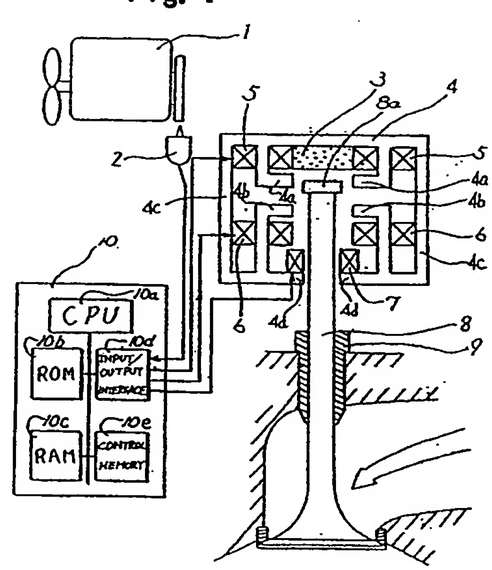
(72) Inventor: **KAWAMURA, Hideo**
**13-5, Okada 8-chome, Samukawa-machi**
**Koza-gun, Kanagawa 253-01(JP)**

(74) Representative: **Brunner, Michael John et al**
**GILL JENNINGS & EVERY 53-64 Chancery Lane**
**London WC2A 1HN(GB)**

(54) **ELECTROMAGNETIC VALVE ACTUATOR.**

(57) A valve actuator to open and close the intake and exhaust valves of an engine utilizing the electromagnetic force generated by an electromagnet. A reciprocally moving magnetic pole (8a) is coupled to an intake or exhaust valve (8), an upper fixed permanent magnetic pole (3) is provided to be opposed to an end in the reciprocating direction of the moving magnetic pole (8a), and the intake or exhaust valve (8) is opened and is closed by the electromagnetic attractive and repelling forces acting between the moving magnetic pole (8a) and the upper fixed permanent magnetic pole (3). The polarity of the moving magnetic pole can be changed depending upon the condition of flowing currents to a first coil (5), a second coil (6) and a third coil (7). Therefore, the timings for opening and closing the intake or exhaust valve (8) is controlled depending upon the operation condition of the engine (1).

Fig. 1




EP 0 422 228 A1

# ELECTROMAGNETIC VALVE ACTUATING SYSTEM

## Technical Field

The present invention relates to an electromagnetic valve actuating system for opening and closing intake and exhaust valves of an engine under electromagnetic forces generated by an electromagnet.

## Background Art

Some conventional actuating systems for opening and closing intake and exhaust valves include a single camshaft which has cams for the intake and exhaust valves, the camshaft being disposed above or laterally of an engine. The camshaft is operatively connected to the crankshaft of the engine by a rotation transmitting means such as a belt, so that the camshaft can rotate synchronously with the rotation of the engine.

The valves have stems whose ends are pressed by cam surfaces of the camshaft through a link mechanism such as rocker arms or push rods. The intake and exhaust valves are normally closed by springs, and can be opened when their stem ends are pressed by the cam surfaces.

Alternatively, an intake camshaft having cams for acting on intake valves and an exhaust camshaft having cams for acting on exhaust valves are disposed above an engine. The intake and exhaust valves are opened when the stem ends of the intake valves are directly pushed by the cam surfaces of the intake camshaft and the stem ends of the exhaust valves are directly pushed by the cam surfaces of the exhaust camshaft.

Therefore, the above conventional actuating systems for opening and closing intake and exhaust valves include camshafts and link mechanisms added to the engine, which is thus necessarily large in size.

Since the camshafts and the link mechanisms are driven by the output shaft of the engine, the engine output power is partly consumed due to the frictional resistance produced when the camshafts and the link mechanisms are driven by the engine. As a result, the effective engine output power is reduced.

The timing with which the intake and exhaust valves are opened and closed cannot be altered during operation of the engine, but the valve opening and closing timing is preset such that the engine operates with high efficiency when it rotates at a predetermined speed. Therefore, the engine output power and efficiency are lower when the engine rotates at a speed different from the predetermined speed.

To solve the above problems, there have been proposed valve actuating systems for opening and closing intake and exhaust valves under electromagnetic forces from electromagnets, rather than with camshafts, as disclosed in Japanese Laid-Open Patent Publications Nos. 58-183805 and 61-76713.

However, the coils of the electromagnets disclosed in the above publications must be supplied with large electric energy in order to generate electromagnetic forces large enough to actuate the intake and exhaust valves, and hence the coils radiate a large amount of heat. As the electromagnets are associated with a cooling unit having a considerable cooling capacity, the problem of the large engine size still remains unsolved.

## Disclosure of the Invention

In view of the aforesaid problems, it is an object of the present invention to provide an electromagnetic valve actuating system for opening and closing intake and exhaust valves of an engine under electromagnetic forces from an electromagnet, rather than with a camshaft, the electromagnet being high in efficiency and output.

According to the present invention, there is provided an electromagnetic valve actuating system comprising a movable magnetic pole coupled to an intake/exhaust valve, the movable magnetic pole being reciprocally movable; an upper fixed permanent magnet confronting one end of the movable magnetic pole, a first intermediate fixed magnetic pole coupled to the upper fixed permanent magnet and confronting the upper fixed permanent magnet, a second distal fixed mag netic pole coupled to the upper fixed permanent magnet and capable of confronting the end of the movable magnetic pole when the valve is open, a distal fixed magnetic pole coupled to the second intermediate fixed magnetic pole and confronting a side of the movable magnetic pole, a first coil for generating a magnetic flux passing through the first intermediate fixed magnetic pole, a second coil for generating a magnetic flux passing through the second intermediate fixed magnetic pole, and a third coil for generating a magnetic flux passing through the movable magnetic pole.

The movable magnetic pole is attracted to the upper fixed permanent magnet to keep the intake/exhaust valve closed. To open the intake/exhaust valve, a magnetic path is produced between the movable magnetic pole and the sec-

ond intermediate fixed magnetic pole, developing a repelling force acting between the upper fixed permanent magnet and the movable magnetic pole. To close the intake/exhaust valve, the movable magnetic pole is attracted again by the upper fixed permanent magnet.

The forces tending to open and close the intake/ exhaust valve are therefore rendered strong, and the actuating system may be reduced in size.

## Brief Description of the Drawings

Fig. 1 is a block diagram showing an electromagnetic valve actuating system according to an embodiment of the present invention;

Fig. 2 is a perspective view showing a magnetic body and a valve in vertical cross section;

Figs. 3(a) through 3(d) are diagrams showing the flow of magnetic lines of force within the magnetic body; and

Fig. 4 is a diagram showing the relationship the crankshaft angle and the valve lift.

## Best Mode for Carrying Out the Invention

An embodiment of the present invention will hereinafter be described in detail with reference to the drawings.

Fig. 1 is a block diagram showing an actuating system according to an embodiment of the present invention, and Fig. 2 shows in cross-sectional perspective an actuator of the actuating system.

An engine 1 has an output shaft, adjacent to which there is disposed a rotation sensor 2 for detecting the rotational speed and phase of the output shaft and converting the detected speed and phase into a signal. The engine 1 has intake and exhaust ports which are opened and closed by intake and exhaust valves, respectively. Of these intake and exhaust valves, the intake valve will mainly be described below.

An intake valve 8 is made of a magnetic material. The intake valve 8 is axially slidably supported by a valve guide 9.

The intake valve 8 has a stem end 8a made of a magnetic material. The stem end 8a is confronted by a per manent magnet 3 which is connected to a central upper portion of a magnetic body 4.

The magnetic body 4 has first intermediate fixed magnetic poles 4a positioned on the lefthand and righthand sides of the permanent magnet 4, and second intermediate fixed magnetic poles 4b disposed below the first intermediate fixed magnetic poles 4a, respectively, in confronting relation thereto.

First coils 5 are disposed respectively around the first left and right intermediate fixed magnetic poles 4a, and second coils 6 are also disposed respectively around the second intermediate fixed magnetic poles 4b. The magnetic body 4 further has, in its lower portion, distal fixed magnetic poles 4d facing sides of the intake valve 8, and a third coil 7 through which the intake valve 8 is movable as a core.

The rotation sensor 2, the first coils 5, the second coils 6, and the third coil 7 are electrically connected to an input/output interface 12d in a control unit 12.

The control unit 12 includes, in addition to the input/output interface 12d which transmits output signals and receives an input signal, a ROM 12b for storing a program and data, a CPU 12a for effecting arithmetic operations under the control of the program stored in the ROM 12b, a RAM 12c for temporarily storing the input signals and the results of arithmetic operations, and a control memory 12e for controlling the flow of signals in the control unit 12.

Operation of the electromagnetic valve actuating system according to the present invention will be described below.

Figs. 3(a) through 3(d) show the flow of magnetic lines of force in the magnetic body 4. Fig. 3(a) shows the flow of magnetic lines of force when the valve is to be closed, Fig. 3(b) shows the flow of magnetic lines of force when the valve starts being opened from the closed condition, Fig. 3(c) shows the flow of magnetic lines of force when the valve remains open, and Fig. 3(d) shows the flow of magnetic lines of force when the valve starts being closed from the open condition.

In Fig. 3(a), the third coil 7 is energized to generate downward magnetic lines of force in the stem of the intake valve 8. The generated magnetic lines of force flow from the stem of the intake valve 8 to the distal fixed magnetic poles 4d and then through bypasses 4c to the permanent magnet 3.

Since the direction of the magnetic lines of force of the permanent magnet 3 is the same as the direction of the magnetic lines of force generated by the third coil 7, these magnetic lines of force are combined with each other, and flow through a magnetic path which extends from the stem end 8a of the intake valve 8 through the stem thereof back again to the distal fixed magnetic poles 4d.

When the magnetic lines of force flow from the permanent magnetic pole 3 to the stem end 8a, an S pole is cre ated on the stem end 8a. Therefore, attractive forces are produced between the N pole of the permanent magnet 3 which faces the stem end 8a, pulling the intake valve 8 upwardly.

In the position in which the head of the intake

valve 8 contacts the valve seat, the intake valve 8 remains closed.

As shown in Fig. 3(b), when the crankshaft angle as detected by the rotation sensor 2 reaches the timing to open the intake valve 8, the third coil 7 is de-energized, and the second coils 6 are energized to generate downward magnetic lines of force in the second intermediate fixed magnetic poles 4b. The generated magnetic lines of force flow through a magnetic path which extends from the second intermediate fixed magnetic poles 4b to the distal fixed magnetic poles 4d, and then from the stem end 8a back to the second intermediate fixed magnetic poles 4b.

When the magnetic lines of force flow from the stem end 8a to the second intermediate fixed magnetic poles 4b, an N pole is created on the stem end 8a and S poles are created on the second intermediate fixed magnetic poles 4b.

Therefore, attractive forces are produced between the stem end 8a and the second intermediate fixed magnetic poles 4b, enabling the intake valve 8 to start moving in the opening direction.

As shown in Fig. 3(c), the intake valve 8 moves in the opening direction to the extent that the stem end 8a and the left and right second intermediate fixed magnetic poles 4b are lined up. In such an aligned condition, the gap between the stem end 8a and the second intermediate fixed magnetic poles 4b is minimum, and the attractive forces are maximum.

Therefore, the speed at which the intake valve 8 moves in the opening direction is reduced, and the intake valve 8 is held in the condition shown in Fig. 3(c).

As shown in Fig. 3(d), when the crankshaft angle as detected by the rotation sensor 2 reaches the timing to close the intake valve 8, the second coils 6 are de-energized, and the first coils 5 are energized to generate downward magnetic lines of force in the first intermediate fixed magnetic poles 4a. The direction of the magnetic lines of force generated by the first coils 5 are the same as the direction of the magnetic lines of force generated by the permanent magnet 3, and these magnetic lines of force are combined and flow through the stem end 8a to the intake valve 8.

The magnetic lines of force flowing toward the intake valve 8 pass through a magnetic path extending through the distal fixed magnetic poles 4d and the bypasses 4c and branched to the first intermediate fixed magnetic poles 4a and the permanent magnet 3.

At this time, N poles are created on the face of the permanent magnet 3 facing the stem end 8a and the left and right first intermediate fixed magnetic poles 4a, and an S pole is created on the stem end 8a.

Therefore, the intake valve 8 is attracted to the permanent magnet 3 and the first intermediate fixed magnetic poles 4a, thus starting to move in the closing direction.

Upon elapse of a first preset time from the timing to close the intake valve 8, the condition (b) is reached, i.e., only the second coils 6 are energized. The intake valve 8 is now subjected to attractive forces, and its movement in the closing direction is decelerated.

The intake valve 8 is thus decelerated in order to lessen shocks imposed when the head of the intake valve 9 is seated on the valve seat.

Upon elapse of a second preset time which is longer than the first preset time, the condition shown in Fig. 3(a) is reached, i.e., only the third coil 7 is energized to attract the intake valve 8 in the closing direction, thus closing the intake port. The intake valve 8 remains closed until the crankshaft angle of the engine 1 reaches the next opening timing.

Fig. 4 shows a so-called cam profile curve. The horizontal axis of the graph indicates the crankshaft angle of the engine, and the vertical axis indicates the valve lift which represents the distance by which the intake valve moves.

The curves in Fig. 4 show the manner in which the valve lift varies as the crankshaft angle varies. The solid-line curve represents changes in the valve lift in the actuating system according to the present invention. The broken-line curve represents changes in the valve lift in the conventional cam-operated actuating system.

At a time I which is the timing to open the intake valve 8, the third coil 7 is de-energized, and the second coils 6 are energized to switch the flow of magnetic lines of force from the condition shown in Fig. 3(a) to the condition shown in Fig. 3(b). The intake valve 8 now moves in the opening direction, while being accelerated, to the position II in which the second intermediate fixed magnetic poles 4b and the stem end 8a are lined up.

When the position II is reached, the intake valve 8 is immediately stopped, and remains open until timing III to close the intake valve 8.

At the timing III, the flow of magnetic lines of force is switched from the condition shown in Fig. 3(c) to the condition shown in Fig. 3(d). Upon elapse IV of the first preset time, the flow of magnetic lines of force is switched from the condition shown in Fig. 3(d) to the condition shown in Fig. 3-(b), decelerating the intake valve 8 in the closing direction. Upon elapse V of the second preset time, the flow of magnetic lines of force is switched from the condition shown in Fig. 3(b) to the condition shown in Fig. 3(a). The intake valve 8 now remains closed until next opening timing.

As shown in Fig. 4, the total opening area of

the intake port, which is expressed as an area surrounded by the horizontal axis and the profile curve, is greater with the valve opening and closing operation of the present invention than with the conventional valve opening and closing operation. Therefore, any resistance to intake air is reduced, allowing intake air to be introduced quickly.

The first and second preset times are determined as follows: A table of preset times and engine rotational speeds is stored in advance in the ROM 12b, and a preset time corresponding to a certain engine rotational speed is determined from the table based on the engine rotational speed.

The ROM 12 may store a map of engine rotational speeds and valve opening and closing timing values I and III, so that the valve opening and closing timing may be varied as the engine rotational speed varies.

Furthermore, an engine cylinder control process for increasing or reducing the number of engine cylinders that are in operation depending on the rotational speed of the engine can be carried out.

The magnetically interrupted portions of the magnetic path, the distance between the distal fixed magnetic poles 4d and the intake valve 8 are small irrespective of whether the valve is opened or closed, and hence any leakage of magnetic lines of force from the magnetic path is small. Accordingly, the electromagnetic forces acting on the intake valve 8 is strong, with the result that the efficiency with which the electromagnetic forces are generated is increased, and the amount of heat generated by the coils is reduced.

While the intake valve has been described above, the actuating system of the present invention is also applicable to the exhaust valve, which is omitted from illustration.

Although a certain preferred embodiment has been shown and described, it should be understood that the present invention should not be limited to the illustrated embodiment but many changes and modifications may be made therein without departing from the scope of the appended claims.

## Industrial Applicability

As described above, the electromagnetic valve actuating system according to the present invention can be used as a system for actuating intake and exhaust valves of an engine, and suitable for use with an engine which is required to vary the timing to open and close the intake and exhaust valves freely depending on changes in an operating condition such as the engine rotational speed.

## Claims

1. An electromagnetic valve actuating system for opening and closing intake and exhaust valves of an engine, comprising:
a movable magnetic pole (8a)coupled to a valve (8), said movable magnetic pole (6) being reciprocally movable;
an upper fixed permanent magnet (3) confronting one end of said movable magnetic pole;
a first intermediate fixed magnetic pole (4a) coupled to said upper fixed permanent magnet and confronting said upper fixed permanent magnet;
a first distal fixed magnetic pole (3c) coupled to said intermediate fixed magnetic pole and confronting the other end of said movable magnetic pole;
a second distal fixed magnetic pole (4b) coupled to said upper fixed permanent magnet and capable of confronting the end of said movable magnetic pole when the valve is open;
a distal fixed magnetic pole (4d) coupled to said second intermediate fixed magnetic pole and confronting a side of said movable magnetic pole;
a first coil (5) for generating a magnetic flux passing through said first intermediate fixed magnetic pole;
a second coil (6) for generating a magnetic flux passing through said second intermediate fixed magnetic pole;
a third coil (7) for generating a magnetic flux passing through said movable magnetic pole; and
energization control means (10) for energizing said first, second, and third coils to open and close said valve.

2. An electromagnetic valve actuating system according to claim (1), wherein said valve is made of a magnetic material.

3. An electromagnetic valve actuating system according to claim (1), wherein said energization control means applies a repelling force acting between said upper fixed permanent magnet and said movable magnetic pole before said valve is seated, thereby lessening shocks produced when the valve is seated.

4. An electromagnetic valve actuating system according to claim (1), wherein the timing established by said energization control means to open and close the valve is variable as the rotational speed of the engine varies.

Fig. 1

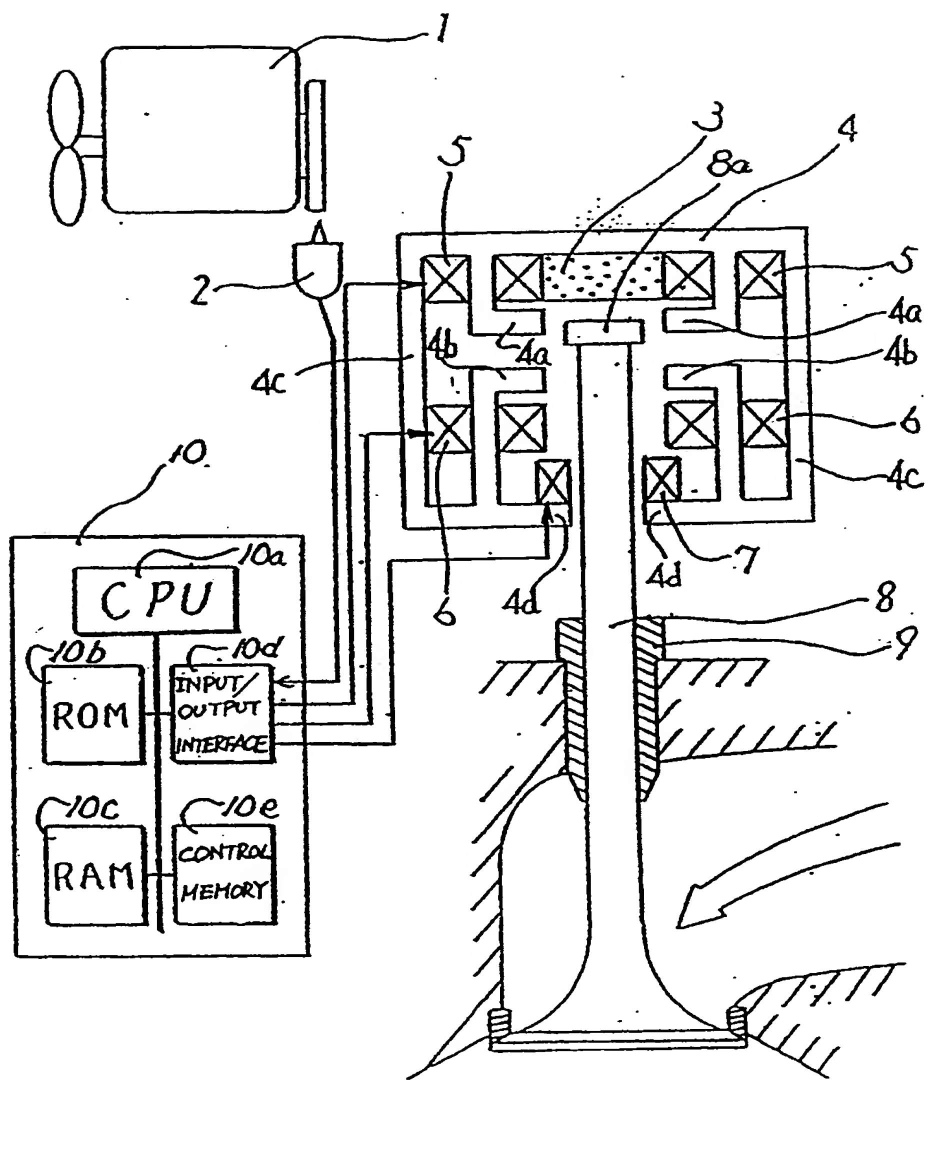

1
2
3
8a
4
5
5
4a
4b
4a
4b
4c
6
4c
10
10a
CPU
7
4d
4d
6
8
9
10b
10d
ROM
INPUT/
OUTPUT
INTERFACE
10c
10e
RAM
CONTROL
MEMORY

Fig. 2

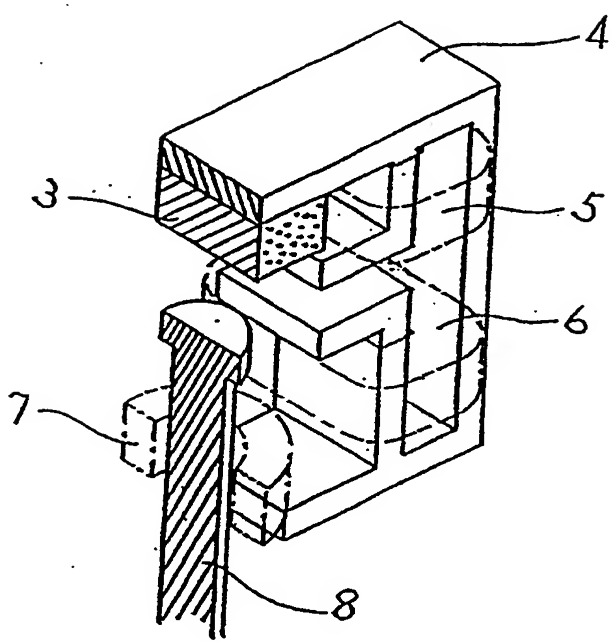
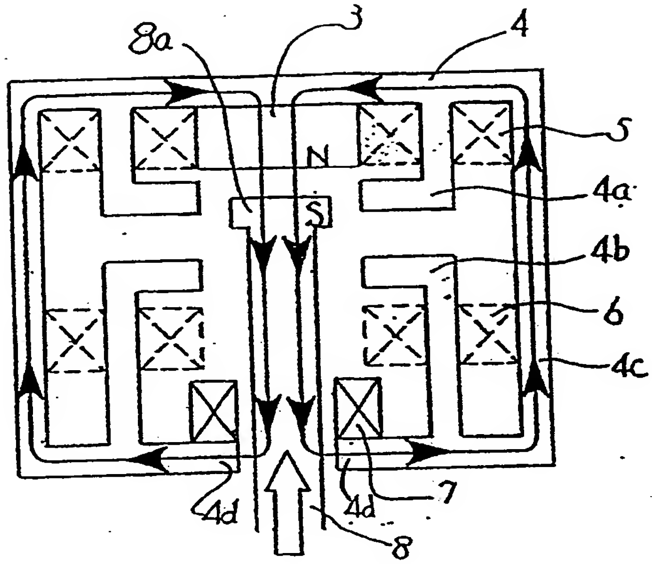


Fig. 3

(a)




(b)

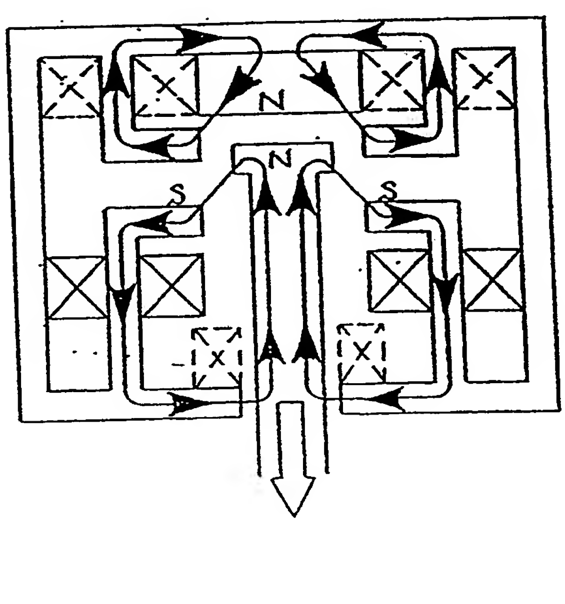


Fig. 3

(c)

(d)

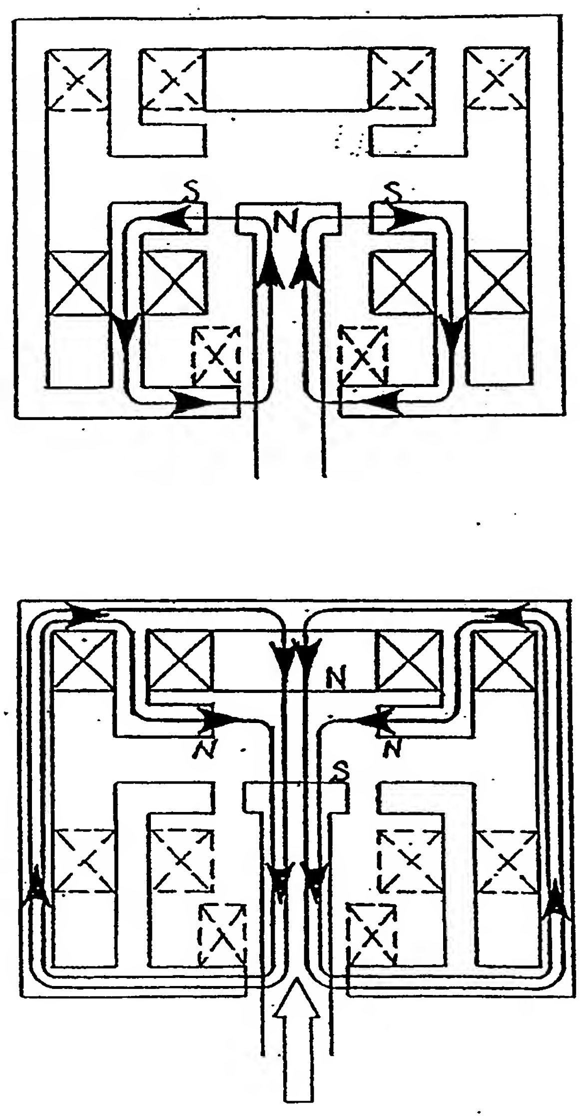
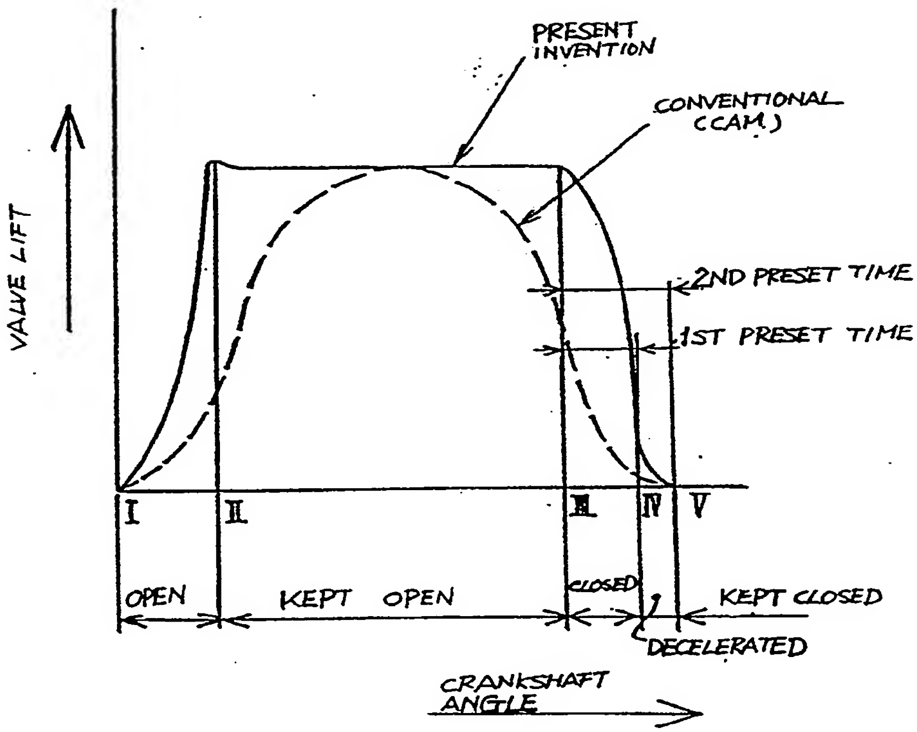


Fig. 4


PRESENT INVENTION
CONVENTIONAL (CAM)
VALVE LIFT
2ND PRESET TIME
1ST PRESET TIME
I
II
III
IV
V
OPEN
KEPT OPEN
CLOSED
KEPT CLOSED
DECELERATED
CRANKSHAFT ANGLE

# INTERNATIONAL SEARCH REPORT

International Application No PCT/JP89/01333

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl$^5$ F01L9/04, F16K31/06, H01F7/16

**II. FIELDS SEARCHED**

Minimum Documentation Searched [7]

| Classification System | Classification Symbols |
|---|---|
| IPC | F01L9/04, F16K31/06, H01F7/16 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

| | |
|---|---|
| Jitsuyo Shinan Koho | 1926 - 1988 |
| Kokai Jitsuyo Shinan Koho | 1971 - 1988 |

**III. DOCUMENTS CONSIDERED TO BE RELEVANT** [9]

| Category * | Citation of Document, [11] with indication, where appropriate, of the relevant passages [12] | Relevant to Claim No. [13] |
|---|---|---|
| A | JP, A, 58-183805 (Honda Motor Co., Ltd.), 27 October 1983 (27. 10. 83), Column 5, lines 10 to 18 (Family: none) | 1, 4 |
| A | JP, B2, 57-31285 (Jidosha Kogai Anzen Kiki Gijutsu Kenkyu Kumiai), 3 July 1982 (03. 07. 82), Fig. 1 (Family: none) | 1 |
| A | JP, U, 51-25215 (The Nippon Signal Co., Ltd.), 24 February 1976 (24. 02. 76), (Family: none) | 1 |
| A | JP, A, 58-101206 (Aichi Machine Industry Co., Ltd.), 16 June 1983 (16. 06. 83), (Family: none) | 1 |

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| January 30, 1990 (30. 01. 90) | February 19, 1990 (19. 02. 90) |
| **International Searching Authority** | **Signature of Authorized Officer** |
| Japanese Patent Office | |

Form PCT/ISA/210 (second sheet) (January 1985)

**FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET**

| | | |
|---|---|---|
| A | JP, A, 56-23507 (Toshiba Corp.), 5 March 1981 (05. 03. 81), (Family: none) | 2 |
| A | JP, A, 61-76713 (Mazda Motor Corporation), 19 April 1986 (19. 04. 86), Column 1, lines 5 to 10 (Family: none) | 3 |

**V.☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]**

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.☐ Claim numbers , because they relate to subject matter not required to be searched by this Authority, namely:

2.☐ Claim numbers , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3.☐ Claim numbers , because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

**VI.☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]**

This International Searching Authority found multiple inventions in this international application as follows:

1.☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

THIS PAGE BLANK (USPTO)